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(54) **Epoxy resin compositions containing red phosphorus**

(57) Curable epoxy resin composition comprising a bisphenol based epoxy resin having between 1.1 and 2.5 epoxy groups on average per molecule, a polyhydric phenol curing agent having more than two phenolic hydroxyl groups on average per molecule and red phosphorus. Also are described a process for the production of such curable epoxy resin compositions, the use of the compositions, especially in the impregnation of fibrous fibres, and products comprising or coated by the partly cured or cured epoxy resin compositions, especially impregnated fibrous fibres and laminates made therefrom.

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## Description

The present invention relates to curable epoxy resin compositions comprising an epoxy resin, a polyhydric phenol curing agent and red phosphorus, to a process for the preparation of such resins, to the use of such resins and to products comprising or coated by the partly cured or cured epoxy resin compositions.

There is a continuing interest in the industry for self-extinguishing and non-burning resinous materials, for example, for surface coatings, castings, moulded articles, and in particular for laminates for use in electrical equipment. The excellent physical, chemical and electrical properties of cured polyepoxides make these compounds extremely suitable for the above applications. However, the usual polyepoxides are, as most organic materials, flammable. Therefore, many attempts have been made to improve the flame retardancy of this class of resins. One of the most widely investigated fields of research to improve the flame retardancy has been the incorporation of chlorine or bromine containing resin compounds as halogenated polyepoxide compounds or halogenated curing compounds. Further, also the use of chlorine and bromine containing additives has been widely studied. Nowadays, however, from an environmental point of view the use of halogenated compounds is less desired. Thus, there is an active interest to look for non-halogenated fire retardants.

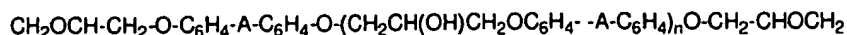
The use of red phosphorus in a process for imparting flame proofing properties to polyepoxides is known from US patent 3,477,982. It has been described in this document that resin compositions having a good flame retardancy can be obtained by mixing especially glycidyl polyethers of polyhydric phenols and polycarboxylic anhydrides or amino compounds having at least two amino hydrogen atoms per molecule with finely divided red phosphorus. Preferably 6 to 25 parts by weight of finely divided red phosphorus per 100 parts by weight of polyepoxide is used (column 1, line 70). From Table IX it is indeed clear that, in order to obtain good extinction times at least 6 weight percent of phosphorus is necessary. Please note that in the other examples usually 8 to 11 percent by weight on resin composition is used. The compositions described in this document, either as such or in combination with a solvent, may be used for the impregnation of glass fibre materials for the preparation of preregs, which can be used for making laminates.

In European patent application 428,863 it has been described that in view of the high amounts of red phosphorus necessary to reach the required flame retardancy (more than 15 percent based on resin) it is hardly possible to reach the requirements with respect to the E-corrosion resistance (page 4, lines 32 ff.). It is further indicated that also the combination of red phosphorus and metal oxides, carbonates or hydroxides does not result in epoxy resin systems having the UL 94V required V-0 flame resistancy. In Example 6 epoxy resins are prepared from an epoxidized novolac in combination with a novolac curing agent. The results of the flame retardancy properties of the resins made are shown in Table 6. It appears that acceptable results are only obtained when using large amounts of red phosphorus (15 percent, Example 12) or by using the combination of red phosphorus and alumina (7.5 percent each, Examples 13 and 14). To solve the problem of the high amounts of red phosphorus to obtain the required flame resistancy this document describes the use of very specific amine curing agents, in combination with an aromatic and/or heterocyclic polyepoxy resin. This specific combination shows the required flame resistancy when an amount of up to 5 percent red phosphorus is used.

It has now surprisingly been found that epoxy resins having good flame retardancy properties and comprising only relatively low amounts of red phosphorus can be obtained by using the combination of a bisphenol based epoxy resin having between 1.1 and 2.5 epoxy groups on average per molecule and a polyhydric phenol curing agent having more than two phenolic hydroxyl groups on average per molecule. Cured resins having a V-0 classification according to the UL 94V are obtained when using amounts of for instance between 2 and 5 percent red phosphorus. A very suitable epoxy resin is the diglycidyl ether of bisphenol A, while a very suitable curing agent is a novolac resin having on average between three and four phenolic hydroxyl groups. The cured products further show an excellent heat resistance, especially in comparison with resins made from brominated resins or curing agents.

Thus, the present invention relates to curable epoxy resin compositions comprising a bisphenol based epoxy resin having between 1.1 and 2.5 epoxy groups on average per molecule, a polyhydric phenol curing agent having more than two phenolic hydroxyl groups on average per molecule and red phosphorus. Suitably, the epoxy resin has between 1.5 and 2.2 epoxy groups on average per molecule, more suitably between 1.8 and 2.1 epoxy groups on average per molecule. Preferably the epoxy resin is the reaction product of a bisphenol and an epichlorohydrin. This reaction is usually carried out in the presence of an alkali hydroxide. Molecular weight, epoxy equivalent, softening point and viscosity of the polyepoxide depend in general on the ratio of epichlorohydrin to polyhydric phenol. Illustrative examples of these reactions and the epoxy compounds thus obtained are described in for instance The Handbook of Epoxy Resins by H. Lee and K. Neville, McGraw-Hill, New York (1967), Epoxy Resins, Chemistry and Technology, edited by C. A. May, Marcel Dekker (1988) and Chemistry and Technology of Epoxy Resins, edited by B. Ellis, Blackie Academic & Professional (1993).

A group of preferred epoxy resin to be used in the curable composition of the present invention has the general formula I



I

in which A is a divalent hydrocarbon group having 1 to 8 carbon atoms,  $-C(O)-$ ,  $-O-$ ,  $-S-$ ,  $-S-S-$ ,  $-S(O)-$ ,  $-S(O)_2-$  or a covalent bond, and n has an average value of 0 to 12. Optionally one or more, especially two or four, methyl groups may be present as substituents of the two phenyl groups in the molecule. More preferably A is methylene or isopropylene and n has an average value from 0 to 2, still more preferably A is isopropylene and n is up to 0.2. These more preferred glycidyl polyethers are usually viscous liquids or semi-solids at 25°C. The viscosity of such glycidyl polyethers may be decreased by mixing with a minor portion, i.e. from 5 to 20 percent by weight of a liquid monoepoxide such as butyl glycidyl ether, phenyl glycidyl ether, stearyl glycidyl ether, or a glycidyl ester of a monocarboxylic acid, such as aliphatic monocarboxylic acids having 9 to 11 carbon atoms per molecule.

The average epoxy equivalent weight is from 140, preferably from 170, up to about 3000, preferably up to 950, more preferably up to about 450.

Especially preferred examples of the epoxy compounds are bisphenol A and bisphenol F, especially bisphenol A, type epoxy compounds having an average epoxy equivalent weight of from 160 to 200. They are commercially available from Shell Chemicals Europe under the trade names EPIKOTE 828, 862 and 806.

Suitably, the polyhydric phenol curing agent to be used in the curable composition of the present invention has between 2.5 and 6 phenolic hydroxyl groups on average per molecule especially between 3.5 and 5 phenolic hydroxyl groups on average per molecule. Very suitably, the polyhydric phenol curing agent is a condensation product of a phenol compound and an aldehyde. Preferably, such a phenol compound is phenol, cresol, bisphenol A, bisphenol F, hydroquinone, resorcinol, methyl resorcinol, tetramethylbiphenol, biphenol, naphthol, dihydroxynaphthalene, more preferably phenol, cresol or bisphenol A. Preferred aldehydes are formaldehyde, acetaldehyde, propionaldehyde and hydroxybenzaldehyde. Especially preferred is the combination of phenol or bisphenol A as the phenol compound and formaldehyde as the aldehyde compound. The condensation of the phenol compound and the aldehyde is usually carried out at temperatures between 40 and 100 °C for periods between 4 and 12 hours under acidic conditions. The preferred phenolic novolac resin curing agents are bisphenol-A novolacs having a weight per phenolic group (WPP) of from 60 to 500, preferably of from 80 to 300. Such phenolic novolacs are commercially available. The phenolic novolac curing agent will be present in the composition in an amount effective to cure the epoxy resin. The ratio between the equivalents of epoxy groups and hydroxyl groups is suitably between 0.25 and 4.0, preferably between 0.5 and 2.0, more preferably about 1. In terms of weight percents, the curing agent will be present in an amount generally from 10 to 70 weight percent, preferably of from 15 to 40, based on the combined weight of epoxy resin and curing agent.

In order to promote faster and/or lower temperature cure of the resin components of the composition, an optional cure accelerator may be used. Many suitable accelerators, such as urea's, tertiary amines, imidazoles, phosphenes, octoates, and boron trifluorides, for example are known in the literature. In this respect reference is also made to the three general references mentioned above. The presently preferred accelerators are the imidazoles, for example 1-methyl imidazole, 2-ethyl imidazole, 2-methyl-4-ethyl imidazole and isopropyl imidazole and tertiary amines. Because of its availability and performance characteristics, 2-methyl imidazole is the preferred accelerator. The accelerator will be present in the composition in an amount effective to increase the cure rate and/or lower the cure temperature of the composition, generally in an amount from 0.001 to 5, preferably from 0.01 to 1 weight percent, based on the weight of the composition.

The compositions may also comprise one or more additives, for instance a solvent or diluent, a filler, pigments, dyes, flow modifiers, thickeners, reinforcing agents, fire retarding or suppressing agents or combinations thereof. A particular useful additive is finely divided silica, such as commercially available under the trade names Aerosil and Cab-O-sil, which can be used in amounts of from 1 to 5 parts per weight per 100 parts by weight of polyepoxide to assist in keeping the finely divided red phosphorus suspended.

The amount of red phosphorus to be used in the compositions according to the present invention is suitably up to 12 percent by weight based on the total resin composition, more suitably up to 10 percent, preferably between 0.5 and 7.5 percent, more preferably between 1.0 and 5.0 percent. The phosphorus is preferably used in the form of finely divided phosphorus, especially 1-40 microns and suitably in a stabilised form. An effective stabiliser is magnesium oxide, which can, for example, be precipitated onto the red phosphorus. In another application the phosphorus is stabilised by a resin (e.g. epoxy resin or phenolformaldehyde resin). The latter composition is commercially available under the trade name MASTERET 70450. Such a grade may have an average particle size of about 11 microns, or 20 microns.

The temperature and the reaction time for the cure of the curable compositions according to the present invention depends on the choice of the polyepoxide and the curing component and the presence of an accelerator. The cure can be carried out in one or more stages, depending on the curing components and the envisaged application. Usual curing temperatures are between 60 and 210 °C, preferably 100-180 °C, and curing times are between 1 minute and 12 hours.

The compositions of the invention can be used for making flame retardant, self-extinguishing or non-burning resinous articles by casting or moulding and allowing to cure. They can also be used for coating a surface, e.g. the surface of a porous fibre laminate, a casting or moulded article with a self-extinguishing or non-burning surface coating. They are preferably used for making fibre reinforced articles by impregnating fibre strands, mat or cloth and allowing to cure. Compositions containing finely dispersed red phosphorus in which the mixture of polyepoxide and curing agent is liquid,

usually after heating or dissolving, may be applied to the fibre material by dipping, spraying, impregnation or brushing and allowing to cure partly or completely directly after the mass has been brought into the desired shape. In cases where a latent curing agent is used, that is a curing agent which provides full cure only at elevated temperature, the resin composition in the fibrous material may be cured partially. Such a partially cured resin is called a B-stage resin and may be used for the preparation of laminates. The resin is still soluble in solvents and fusible. Such a fibrous material may be stored for some time before the eventual laminate is made by curing at elevated temperatures. The fibre material may also be impregnated with a composition according to the present invention in combination with a volatile solvent, whereupon the solvent is evaporated. The resin components may then be allowed to cure partially to give the B-stage resin. Impregnated fibre materials prepared by this method may also be stored for some time, before laminates are prepared from them. Suitable solvents are ketones, such as acetone, and aromatic solvents such as toluene. Partial cure is usually carried out between 80 and 200 °C, especially 120-180 °C, for 30 seconds to 8 minutes. For the preparation of preregs from the compositions of the present invention preferably the process and apparatus as described in European patent 476752 is used, or the processes or apparatuses as described in International patent applications PCT/EP 94/04326, PCT/EP 94/04327 and PCT/EP 94/04328. The preregs thus obtained may be used for the preparation of laminates.

The present invention further relates to a process for the preparation of the curable compositions as described above by mixing the constituents. This is usually done at temperatures between 0 °C and 50 °C, usually 25 °C. Very suitable the epoxy resin is added to the curing agent, whereafter the phosphorus is added. The phosphorus may also be added to one or both of the constituents. Mixing may be carried out using conventional equipment.

The invention further relates to the use of the compositions, especially in the impregnation of fibrous materials. It will be appreciated that the invention also relates to cured or partly cured products obtained by using the compositions of the present invention, especially preregs and laminates.

The following examples illustrate the present invention. Unless otherwise mentioned, all parts and percentages are weight parts and weight percentages.

#### EXAMPLE 1

This example describes the preparation of a red phosphorus containing thermosettable resin composition and its use in the preparation of cured laminates. The resin component was prepared by charging to a reactor 59 g of liquid diglycidyl ether of bisphenol A (EPIKOTE 828, EEW 178-186, 2.0 epoxy groups per molecule), 2 g of solid tetraglycidyl ether of tetraphenylol ethane (EPIKOTE 1031, EEW 200-240), 6.1 g of suspended red phosphorus (MASTERET 70450, 50 percent phosphorus) and 34.9 g phenolnovolak resin (WPP 103-105, about 4-hydroxyl groups per molecule), heating the mixture to 140 °C and stirring for 5 minutes, whereafter 0.05 phr 2-methylimidazole was added. After 3 minutes glass web (200 g/m<sup>2</sup>) was impregnated with the resin composition. The impregnated glass webs were partially cured (160 °C, 5 minutes, 40 percent solids). Laminates were prepared from four layers of preregs (0.9 mm). Testing according to UL 94 showed that the laminates classified as V-0.

#### EXAMPLE 2

Example 1 was repeated, using 63 g of liquid diglycidyl ether of bisphenol A (EPIKOTE 828, EEW 178-186), 2.5 g of solid tetraglycidyl ether of tetraphenylol ethane (EPIKOTE 1031, EEW 200-240), 17.5 g of suspended red phosphorus (MASTERET 70450, 50 percent phosphorus), 17 g diphenylol propane (2-hydroxyl groups per molecule) and 25 g phenolnovolak resin (WPP 103-105, about 4-hydroxyl groups per molecule). Laminates made from four layers of prepreg classified as V-0 according to UL 94.

#### Claims

1. Curable epoxy resin composition comprising a bisphenol based epoxy resin having between 1.1 and 2.5 epoxy groups on average per molecule, a polyhydric phenol curing agent having more than two phenolic hydroxyl groups on average per molecule and red phosphorus.
2. Curable epoxy resin composition according to claim 1, in which the epoxy resin has between 1.5 and 2.2 epoxy groups on average per molecule and the polyhydric phenol curing agent has between 2.5 and 6 phenolic hydroxyl groups on average per molecule.
3. Curable epoxy resin composition according to claim 1 or 2, in which the epoxy resin has the general formula I



I

in which A is methylene or isopropylene and n has an average value from 0 to 2.

4. Curable epoxy resin composition according to any of claims 1 to 3, in which the polyhydric phenol curing agent is a condensation product of a phenol compound and an aldehyde, in which the phenol compound is phenol, cresol,  
5 bisphenol A, bisphenol F, hydroquinone, resorcinol, methyl resorcinol, tetramethylbiphenol, biphenol, naphthol or dihydroxynaphthalene and the aldehyde is formaldehyde, acetaldehyde, propionaldehyde or hydroxybenzaldehyde.
5. Curable epoxy resin composition according to claim 4, in which the phenol compound is phenol or bisphenol A and  
10 the aldehyde is formaldehyde.
6. Curable epoxy resin composition according to any of claims 1 to 5, in which the amount of red phosphorus is up to 10 percent by weight based on the total resin composition, preferably between 0.5 and 7.5 percent by weight based on the total resin composition.
- 15 7. Curable epoxy resin composition according to any of claims 1 to 6, in which the ratio between the equivalents of epoxy groups and hydroxyl groups is between 0.5 and 2.0.
8. Use of a curable epoxy resin composition according to any of claims 1 to 7, in a process for resin impregnation of  
20 fibrous fibres.
9. Fibrous materials impregnated with the partly cured epoxy resin composition according to any of claims 1 to 7.
10. Cured laminates obtained by using the impregnated fibres according to claim 9.



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## EUROPEAN SEARCH REPORT

Application Number  
EP 96 20 1976

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	DATABASE WPI Derwent Publications Ltd., London, GB; AN 90-196912 XP002011741 & JP-A-02 129 234 (KANEBO KK) , 17 May 1990 * abstract *	1-10	C08K3/02 C08L63/00
X	& JP-A-02 129 234 (KANEBO KK) 17 May 1990 * example 10; table 5 *	1-10	
X	PATENT ABSTRACTS OF JAPAN vol. 14, no. 350 (C-0744), 27 July 1990 & JP-A-02 127459 (KANEBO LTD), 16 May 1990, * abstract *	1-10	
X	& JP-A-02 127 459 (KANEBO LTD) 16 May 1990 * example 10; table 5 *	1-10	
D,A	GB-A-1 112 139 (SHELL) * claims *	1	
			TECHNICAL FIELDS SEARCHED (Int.Cl.6)
			C08K C08L
The present search report has been drawn up for all claims			
Place of search THE HAGUE		Date of completion of the search 27 August 1996	Examiner Deraedt, G
<p><b>CATEGORY OF CITED DOCUMENTS</b></p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons</p> <p>&amp; : member of the same patent family, corresponding document</p>			

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